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# Indigenous Lunar Construction Materials

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## Motivation

*The utilization of local resources for the construction and operation of a lunar base can significantly reduce the costs of transporting materials and supplies from Earth.*

- Primary examples of utilization of lunar resources: radiation shielding, oxygen extraction, water production, helium-3 mining.
- **Construction materials** are excellent candidates for utilization of local resources: they are relatively simple, heavy, and available. Raw materials may be by-product of other operations such as oxygen extraction.

### Why

Pay-load weight savings

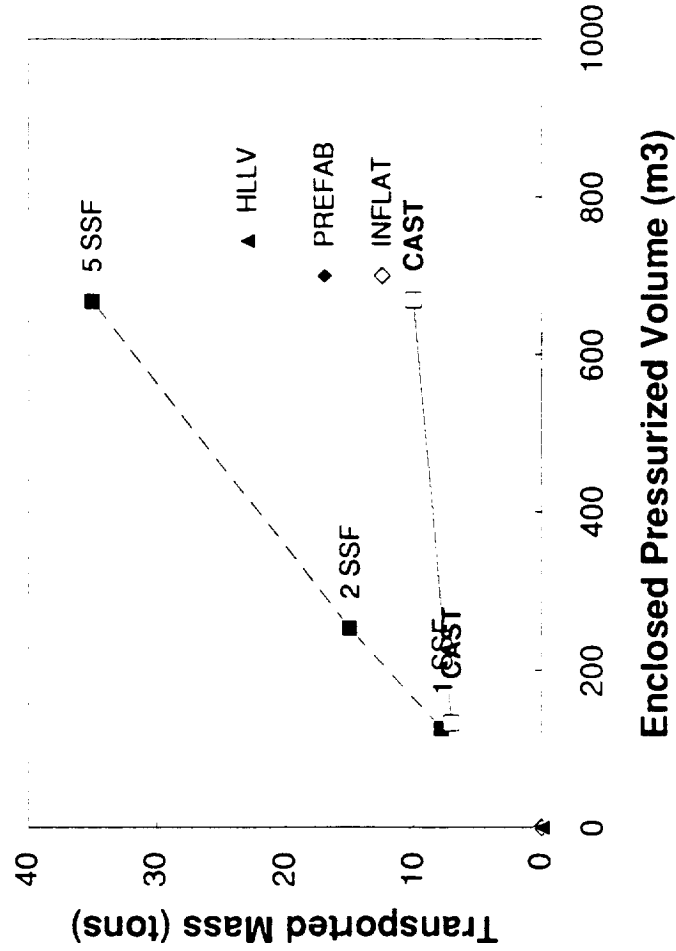
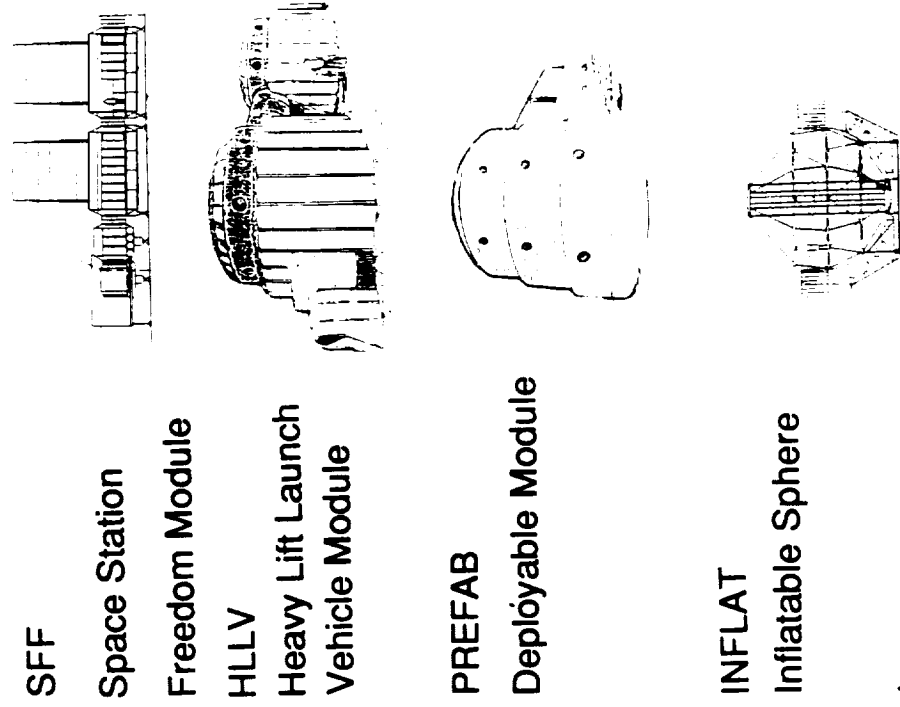
Long term manned presence in space

### Why not

Unfamiliar technologies

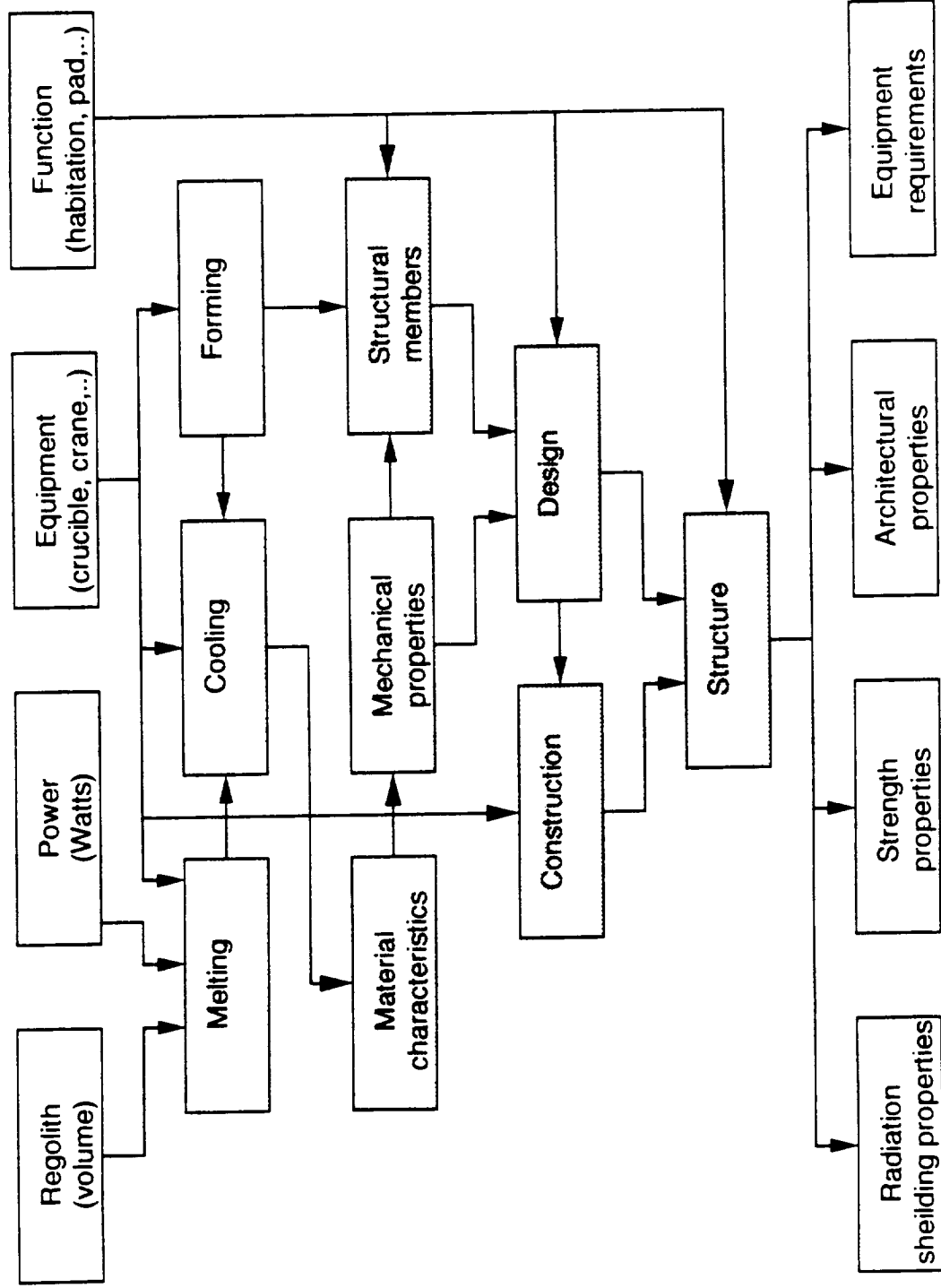
Significant infrastructure

## Comparison of Various Lunar Structures



CAST Cast Regolith Structure

## Processing - material - construction - structure relationships



## **Objectives**

- Investigate the *feasibility* of the use of local lunar resources for construction of a lunar base structure.
- Develop a material processing method and integrate the method with design and construction of a pressurized habitation structure.
- Estimate specifications of the support equipment necessary for material processing and construction.
- Provide parameters for systems models of lunar base constructions, supply and operations.

## Indigenous Lunar Construction Materials

- **Minimally processed materials:** lunar rocks, regolith mortar, compressed regolith, free flowing molten regolith, for domes, roads, and landing pads (Khaliil SCIA). *Materials do not have good mechanical properties.*
- **Solar power fused regolith** for large layered slabs (Clifton). *Solar power is not sufficient to melt large quantities of regolith in reasonable lengths of time.*
- **Sintered and hot pressed regolith** for bricks, plates, columns (Simonds, NASA LSI; Meek, UT; Vaniman, LANL; Sullivan, Battelle). *Small structural components. Not suited to tensile (pressurized) loading conditions or automated construction.*
- **Concrete:** traditional steel reinforced concrete structure using columns, beams, and slabs (Lin, CTL). *Lack of water.*
- **Iron and Steel,** high quality construction materials (UA). *Complex processing methods with high energy requirements.*
- **Cast basalt:** liquified regolith cast into large slab forms (Capps and Wise, Boeing; Binder, Lockheed)

## **Guidelines for Material Processing Method**

- Material processing method should be applicable to a variety of structural element geometries and sizes.
- Processing method should produce a material with good, consistent mechanical properties.
- Amount of material processing-specific support equipment should be minimized.
- Material processing method should be integrated with structural design and construction operations.
- Processing and construction steps should be simple in order to accommodate robotic automation.



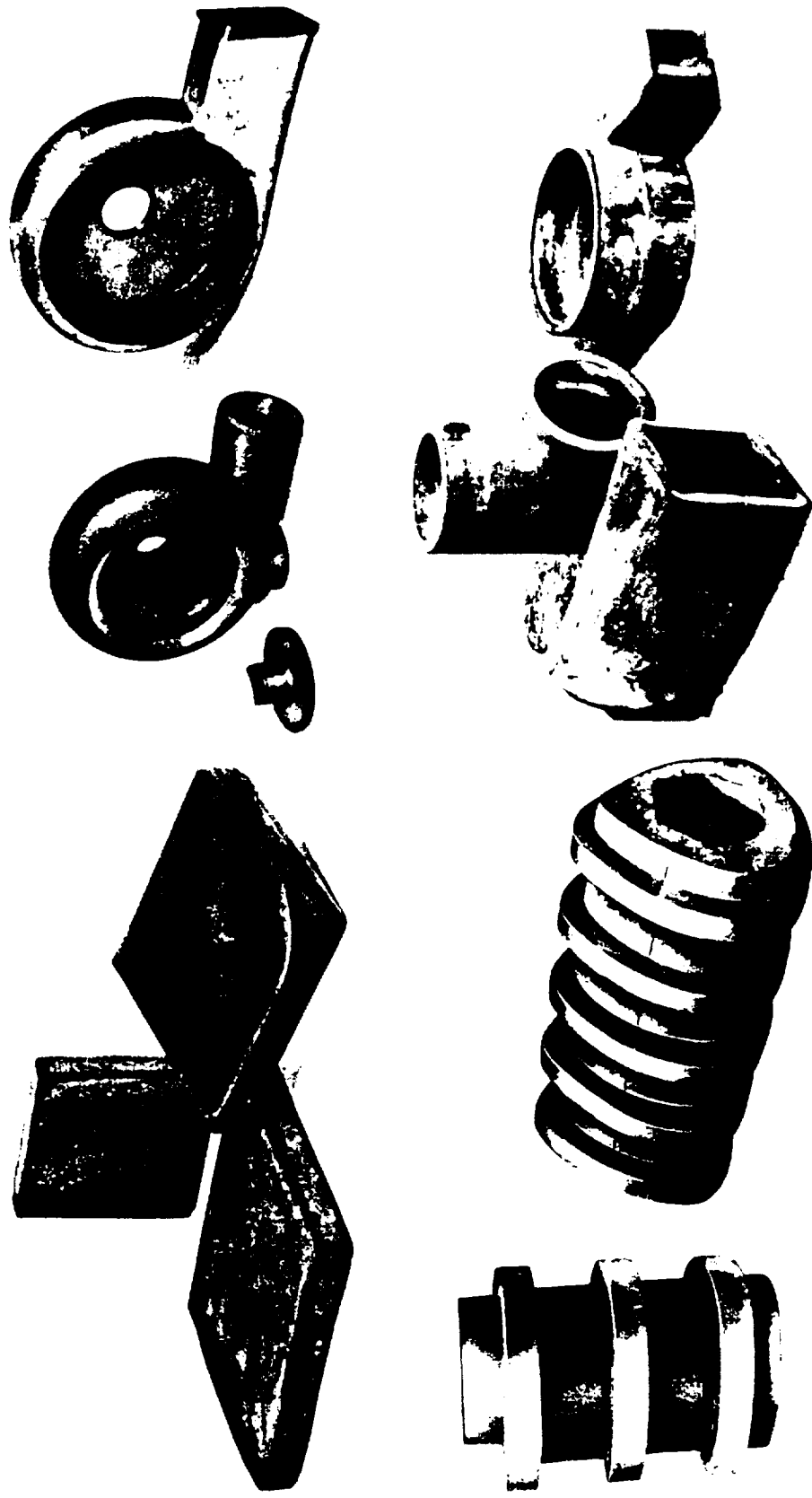
## Assumptions

- Material processing method is intended for far-term lunar base. *A certain level of infrastructure must be in place.*
- **Power source** of 100 kW is available (SP-100 nuclear reactor). *This places tight constraints on processing time and structural component size.*
- **Earth moving equipment** is available. *All scenarios include plans for regolith shielding which requires earth moving.*
- **Lunar crane** with 10 ton capacity is available. *Near-term lunar base construction is likely to require lunar crane.*

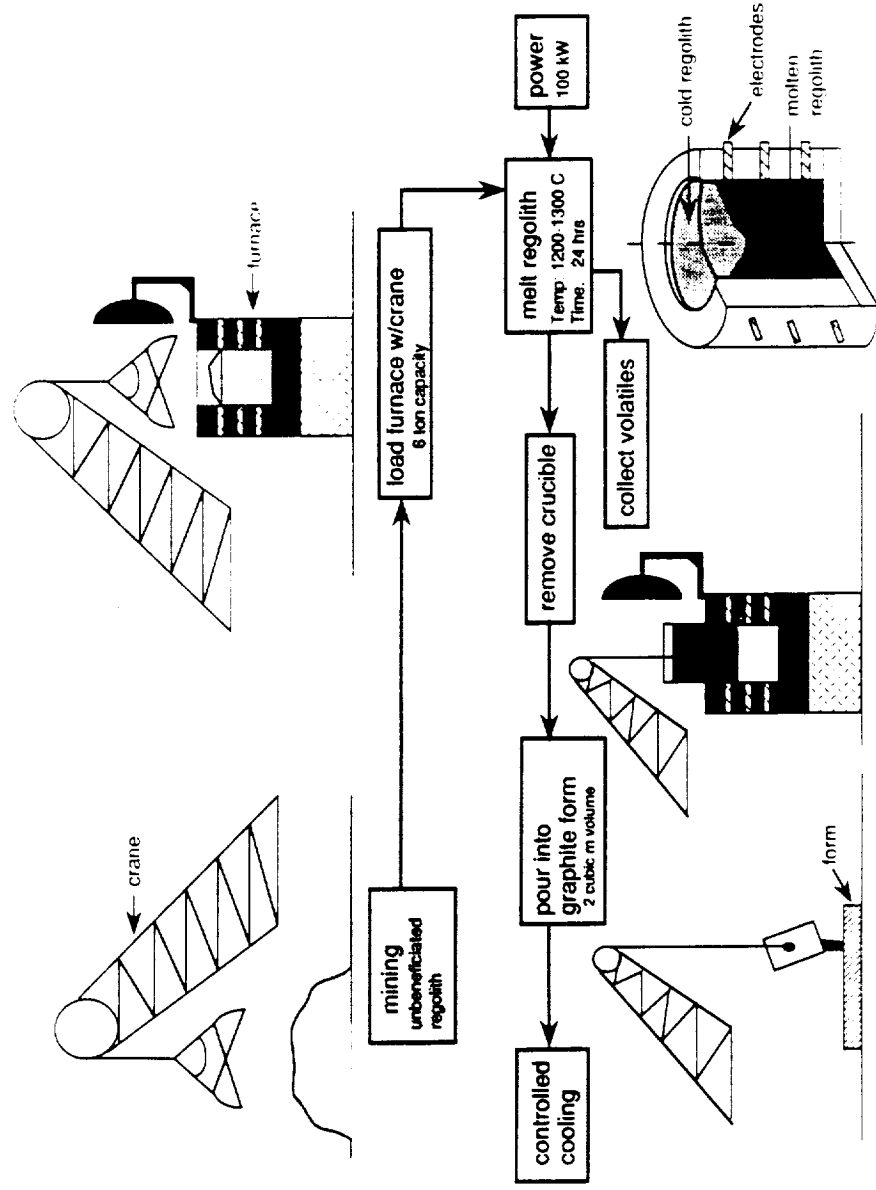
## Cast Lunar Regolith

- **Raw materials:** regolith is abundant over the lunar surface. Chemical composition of regolith is very similar to terrestrial basalts.
- **Terrestrial cast basalt** processing methods are moderately well established. Cast basalt has good mechanical properties and can be formed into complex geometries.
- **Proposed cast regolith** process is a simplification of terrestrial cast basalt suited to the lunar environment. Benification, grinding, homogenization steps are unnecessary. High vacuum and low gravity pose no unusual problems.
- Material processing may be integrated with oxygen production.

## Examples of Cast Basalt Components



## Cast Regolith Process



## Processing Equipment

- **Furnace:** batch operation, electrical resistance, 1300°C capability, 90% efficiency, 3 ton weight, enclosed heating chamber for recovery of volatiles (hydrogen, nitrogen,...). At 100 kW, melting cycle lasts 24 hrs for 6 ton regolith capacity.
- **Ladle:** heating chamber of furnace is removable to act as a ladle for the transfer of molten regolith to casting forms.
- **Casting forms:** reinforced graphite panels, 1500°C capability, 0.5 ton weight. Reflective surfaces reduce radiative heat transfer for controlled cooling and recrystallization over a 24 hr period.

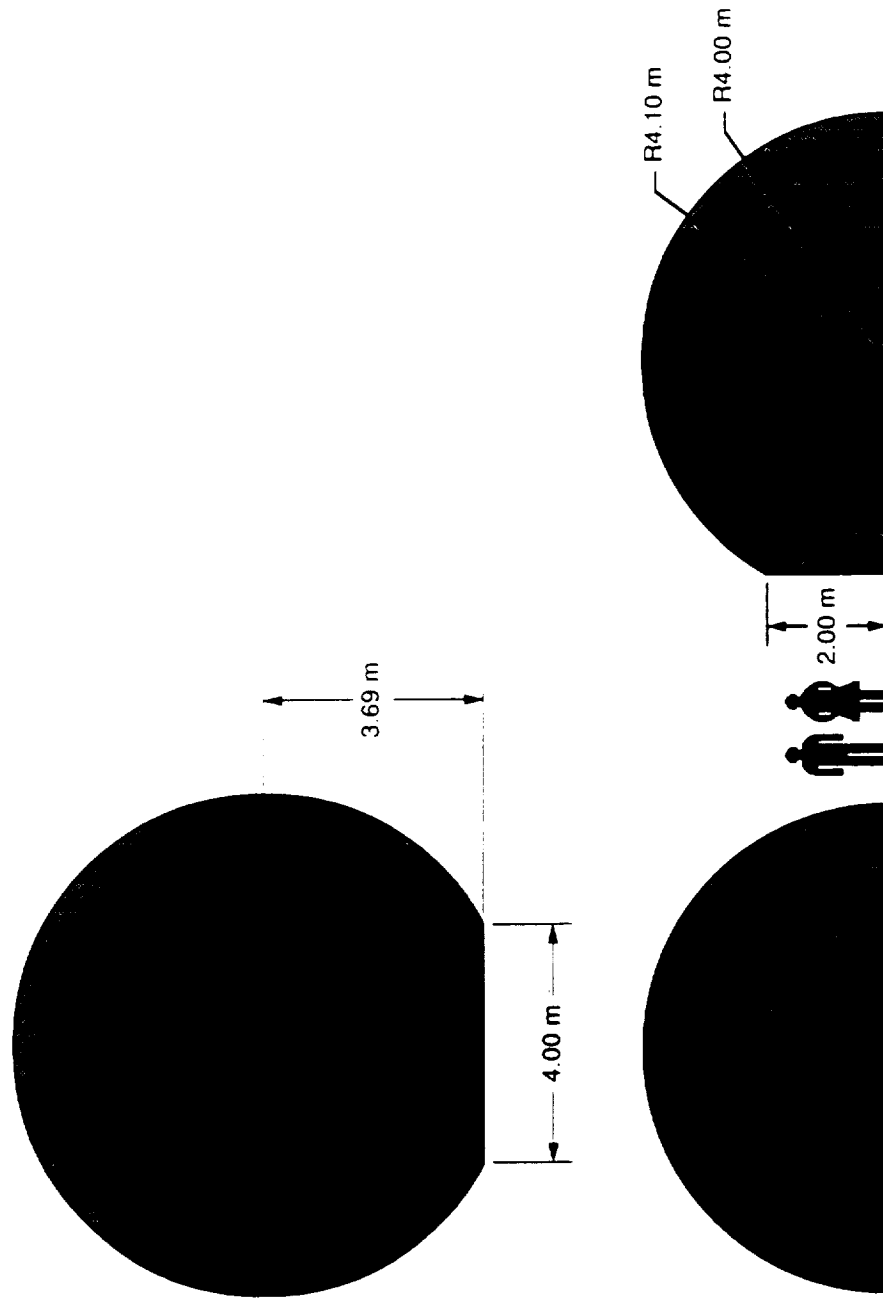
## Mechanical Properties of Cast Basalt

	Cast Regolith	Concrete	Cast Iron	Aluminum
Density (g/cc)	2.9	2.4	7.1	2.8
Elastic Modulus (GPa)	110	21	160	70
Tensile Strength (MPa)	>35	7	125	100*
Fracture Tough. (MPa√m)	2	2	15	25
Thermal Expan. (x10 <sup>-6</sup> /°C)	7.8	13	11	22
Melting Point (°C)	1200	-	1400	600

\* yield

## Material Properties and Structural Design

- **Brittle material.** Design must minimize tensile and bending stresses and stress concentrations. Compression loading is ideal but unrealistic for pressurized structure.
- **Joining** introduces stress concentrations so the minimum number of structural components should be used. The maximum size of a structural element is dictated by the capacity of the batch furnace, casting capabilities, and constructibility.
- **Net shape forming** is necessary because cutting is very difficult.
- Large factors of safety must be avoided to reduce mass of structure and time required for material processing.
- Earth-based structural elements are necessary for joining, reinforcement, and air-locks. Design should minimize these.





## Future Work

- **Material processing demonstration.** Demonstrate liquification, casting characteristics, viscosity, cooling and recrystallization, environmental effects.
- **Material property evaluation:** density, elastic moduli, fracture toughness, statistical measures of strength.
- **Structural design.** Develop a point estimate of a pressurized lunar habitation structure based on cast regolith.
- **Construction methods.** Establish integrated material processing and construction steps. Investigate potential for robotic automation.
- **Scale structural testing.** Validate design models and demonstrate structural reliability of point design.

